NAVAL POSTGRADUATE SCHOOL
Monterey, California
Department of Electrical & Computer Engineering

Laboratory Experiments Booklet

Electromagnetic Engineering
EO2652

Professor David Jenn
Winter 2002

Laboratory Operating Conditions and Policies 2

Help Sheets Available in the Microwave Lab:

Appendix A: dB vs dBm
Appendix B: Measuring VSWR
Appendix C: Using the Slotted Line (0.5-4 GHz)
Appendix D: Reading the SWR Meter
Appendix E: Using the Cavity Frequency Meter
Appendix F: Using the Slotted Line (8-12.4 GHz)
Appendix G: Slotted Line Measurements Using the Smith Chart
Appendix H: Measuring the Voltage Standing Wave Ratio (VSWR)
Appendix I: Using the HP438A Power Meter

Corrections, comments and suggestions for improvement are greatly appreciated.

Assembled: R.L. Vitale
Version: 4
Revised: D. Jenn (1/25/02)

MICROWAVE AND ANTENNA LABORATORY
WINTER QUARTER 2002 (AY02-2)

OPERATING CONDITIONS

<u>Staff</u>: David Schaeffer, Microwave Laboratory Director, 656-3445
        Don Sok, Microwave Laboratory Technician

<u>Equipment Situation</u>:   Laboratory Facilities will permit a limited number of Lab Groups to operate simultaneously. Most experiments allow 4 groups, but others only allow 2. Experiments may require 1-4 hours depending upon expertise of lab group. Laboratory assistance may not always be available due to staffing shortage. Please try to follow the laboratory guidelines posted at the entrance to the Microwave Lab (S-419). Also, because of the staffing shortage, please be patient when requiring assistance. **Assistance will be provided best when you attempt to make an appointment <u>in advance</u>.**

OPERATING POLICY & PROCEDURES

- **SIGN UP EARLY FOR YOUR LAB. <u>SIGN UP BY 12:00 (NOON) OF THE PREVIOUS DAY</u>**. At 1200 hours of the prior day, lab personnel will cross out vacant antenna lab hours. Arrangements to conduct experiments during these crossed out times must be made in person to the Lab Director and will be granted provided support personnel are available. One signup sheet for the Microwave Lab is provided to avoid conflicts between multiple classes.
- **SHOW UP ON TIME FOR YOUR LAB.** If you're going to cancel please notify the lab so others may use it. Lab phone is x3445 and a message machine will pick up for after hours notices.

MICROWAVE LABORATORY FACILITIES

MICROWAVE LAB (ROOM 419, PHONE x3445)
Located on 4th floor. Laboratory experiments are generally performed in this area.

ANTENNA LAB (ROOM 703, PHONE x2561)
Located on 7th floor roof. Take north elevator (where coffee mess is) to roof, turn right & go out door onto 6th deck, turn left, walk about 100 ft and go up ladder to 7th deck, turn left, Room 703 is behind large white satellite dish.

ANECHOIC CHAMBER (ROOM 604, PHONE x2561)
Located on 6th floor roof.   Take north elevator (where coffee mess is) to roof, turn right & go out door onto 6th deck, turn left, walk about 120 ft PAST up ladder, Room 604 is on left. **<u>QUALIFIED MICROWAVE LABORATORY STAFF WILL OPERATE ALL ANECHOIC CHAMBER EQUIPMENT.</u>**

COMPUTATIONAL FACILITIES
The Microwave Lab PCs have several antenna & electromagnetic propagation modeling programs that you can use to verify your experimental data.

NAVAL POSTGRADUATE SCHOOL
Monterey, CA

TRANSMISSION LINE STANDING WAVES

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NOTE

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Allow 1 hour for a separate training exercise to learn slotted line VSWR measurement skills prior to attempting this experiment (see section 5.1). Skills learned in this exercise are used in follow on experiments. Understanding these measurement skills prior to attempting this experiment will save countless hours of frustration in the long run.

This laboratory exercise can take 2 hours to successfully compete. However if you do not understand how to properly operate the equipment or understand how to make VSWR measurements with a slotted line, this exercise can take far longer (*many teams have spent over 8 hours*).

VSWR and SWR are often used interchangeably. When SWR is used, typically the voltage standing wave ratio is implied.

1.0   OBJECTIVE

Part 1: Measure standing wave patterns on a coaxial transmission line (Slotted Line) with various terminations (loads) using a slotted line probe and standing wave ratio (SWR) meter.
Part 2: Determine the VSWR of the Loads used in Part 1 from the slotted line measurements.
Part 3: Measure cable line loss directly using a power meter.

2.0   EQUIPMENT   Setup is shown in Figures 2.

Quantity	Description
1	HP 8620C Sweep Oscillator with 86222A Module (0.01-2.4GHz)
1	HP 805C Slotted Line (0.5 - 4.0 GHz)
1	Attenuator, Variable 0 - 10 dB, Coax N-type connections
1	HP 415E Standing Wave Ratio Meter
1	HP 436A Power Meter with a HP 8482A Power Sensor & Sensor Cord
4	N to N type connecting cables
1	N to GRC adapter
3	Loads: Short, 50 ohms, 200 ohms (GRC type connection)
1	Cable: 100 ft, 50 ohm coax (RG-213/U)
1	Frequency meter

3.0   INTRODUCTION

When the characteristic impedance (Z_0) of a transmission line and the load impedance (Z_L) are not equal, power is reflected backwards from the load towards the generator (source). The interference between the forward traveling waves (from source) and the backward waves

(reflections from load) causes standing waves to be established. These standing waves have distinct characteristics:

- Standing wave minima and maxima are separated by a distance of $\lambda/2$ where λ is the wavelength in the transmission line. For the slotted line the medium is free space, thus $\lambda = c/f$.
- The voltage standing wave ratio (VSWR, often referred to as SWR, or symbolically S) is equal to $|V_{max}|/|V_{min}|$ and depends upon the load impedance terminating the line. The larger the ratio, the greater amount of power is reflected. Always greater than 1.0, values of the VSWR near 1 correspond to a good impedance match; as VSWR gets larger the impedance match becomes worse.
- Locations of standing wave minima also depend on the load. If the line is short circuited, a voltage minimum occurs at the load; if the line is open-circuited, a voltage maximum occurs at the load.

4.0 THEORY

The standing wave ratio at the input of a transmission line (Figure 1) is a function of the terminating load and the line loss and is given in terms of the input reflection by

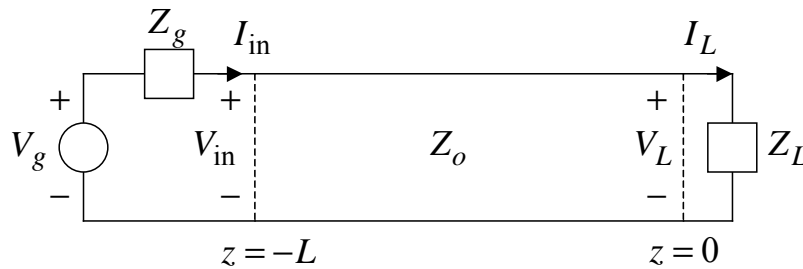$$S_{in} = \frac{1 + |\Gamma_{in}|}{1 - |\Gamma_{in}|} \tag{1}$$

Figure 1: Finite transmission line terminated with a load.

The voltage at a location z' on the line ($z' = 0$ is *at* the load) is the summation of the forward and backward traveling wave and is given by:

$$V(z') = V_o^+ (e^{\gamma z'} + \Gamma_L e^{-\gamma z'}).$$

The reflection coefficient at the load is

$$\Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o}$$

When there is loss in the cable $\gamma = \alpha + j\beta$ and at the transmission line input, the input reflection coefficient magnitude becomes:

4

$$\left|\Gamma_{\text{in}}\right| = \left|\Gamma_L\right| e^{-2\alpha L} \tag{2}$$

where L is the line length (meters) and α is the attenuation constant (Np/m). If the line is lossless then $\alpha = 0$ and

$$|\Gamma_{\text{in}}| = |\Gamma_L|.$$

When line loss is not negligible, it may be calculated by measuring the VSWR when a known load is placed at the end of the line. For example, if a short circuit is applied to the cable end then $Z_L = 0$ and $\Gamma_L = -1$. Thus equation (4) becomes

$$\left|\Gamma_{\text{in}}\right| = e^{-2\alpha L} = \frac{S_{\text{in}} - 1}{S_{\text{in}} + 1} \tag{3}$$

where S_{in} is the measured VSWR at the input to the coaxial cable and $e^{-2\alpha L}$ is the power attenuation on the line of length L. The line loss (in dB) then becomes:

$$\text{Two - way loss in dB} = 10\log(e^{-2\alpha L}) = 10\log\left(\frac{S_{\text{in}} - 1}{S_{\text{in}} + 1}\right) \tag{4}$$

Measurement of the input VSWR can be used to determine the line loss (assuming that the connectors and equipment attached to the system are well matched (i.e., SWRs are close to 1).
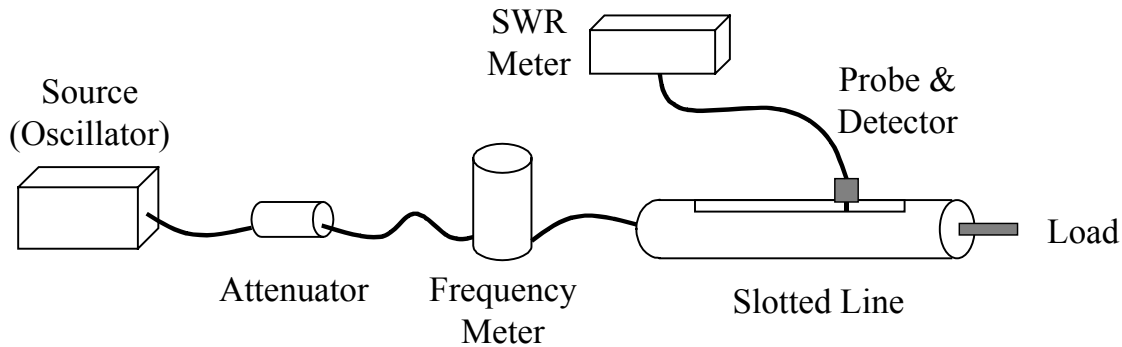
Figure 2: Setup for standing wave pattern measurement.

5.0   PROCEDURE

Part 1: Measure the standing wave pattern for several known loads.
Part 2: Measure the VSWR of several known loads at 1GHz using the slotted line.
Part 3: Measure coaxial cable loss at several frequencies and compare to cable specifications.

Note: When making slotted line measurements, assume that slotted line loss is negligible.

5.1   Preparation

a. Read the following Microwave Lab Help Sheets prior to attempting the experiment.
   - dB vs dBm
   - Quick Start to Slotted Line Measurements

- Measuring VSWR
- Reading the SWR Meter (Learn to use the expand setting properly)
- Using the Slotted Line (0.5-4 GHz) Using the Cavity Frequency Meter

b. Note the following:
- The SWR meter reads out in NEGATIVE dB; larger dB values indicate a smaller signal.
- SWR (VSWR) is a ratio. **You need two measurements for each SWR value (V_{max} and V_{min}).** SWR is V_{max} - V_{min} when the SWR values are in dB.
- Retune the Slotted Line for square law detection after changing frequency or power settings.
- Ensure that the signal generator is set for a single frequency (only the CW light is illuminated). If not, the SWR Meter needle will dance.
- Minima locations on the slotted line are often obscured by the noise floor (50dB range). Use locations of the same dB value point (preferable low) on either side of the relative minima location. Take the center point between those two dB values as the minima location. Example: you have 40dB at 25cm and 40 dB at 29cm, minima location then taken as 27cm.

5.2 Lab Setup and Slotting Line Training

a. Ensure the setup is as shown in Figure 2. Sketch the lab setup for reference.
b. Ensure equipment has the following settings:

Sweep Oscillator Settings		SWR Meter Settings	
Band:	0.01-2.4 GHz	Power:	LINE-ON
Mode:	CW (CW/CW knob illuminated)	Input:	XTAL IMPED HIGH
Markers:	off		
ALC:	INT		
Modulation:	1KHz SQ Wave (Switch on Back)		
Power:	+11dBm		

5.3 Measurements

5.3.1 Part 1: Measure and Plot the Standing Wave Pattern
Objective: Produce normalized plots of standing wave voltage ($|V|/|V_{ref}|$) vs slotted line position for the loads listed below. Note: VSWR is not being measured here, standing wave pattern is. (V_{ref} is a convenient reference value.)

a. Adjust the sweep oscillator for 1GHz constant frequency continuous wave (CW) output.
b. Install a 50 ohm coaxial load on the slotted line and achieve square law operation of the detector *(see Using the Slotted Line (0.5-4GHz) and Quick Start Help Sheets)*. This can be done by adjusting the stub tuner (top black knob) on the slotted line for resonance (maximum deflection) and then adjusting the input power level (on signal generator) until square law detection is achieved.
c. Install the short circuit load (0 ohms) on the load end of the slotted line (see Figure 2).
d. Find the peak of the standing wave by sliding the probe up/down the slotted line and observing

the SWR meter. Peak occurs at maximum needle deflection (to right -- remember you are measuring negative dB). Adjust range knob on SWR meter as necessary to observe peak.

e. Normalize the standing wave peak to a convenient reference value, V_{max}. This is done with the probe located at the standing wave peak, adjust the gain knobs on the SWR meter to place the needle at a convenient reference point (0dB + range setting, usually 30dB). This point is considered s_{ref} for the shorted load (lower case s represents a normalized dB value). Record the reference value s_{ref} in dB on Data Sheet 1 for later reference.

f. Slide the probe up/down the slotted line. Measure the standing wave value (s in dB) relative to the standing wave reference peak (s_{ref}) vs distance along the slotted line. The SWR (s) is the difference between s_{ref} and the standing wave value at the current position (in dB). Make more frequent measurements around areas of minima and maxima standing wave values as changes occur more rapidly there. Record on Data Sheet 1 the standing wave value measurements (s) and determine the ($/V/|V_{max}|$) values by the following equation:

$$\frac{|V|}{|V_{max}|} = 10^{-(s_{dB}/20)}$$

g. Repeat steps b-f for the additional loads below (200 and 50 ohms). Plot each $|V|/|V_{max}|$ vs slotted line position on the same graph. Ensure the standing wave is normalized to the reference point (s_{ref}) and record this point on Data Sheet 1. Obtain the standing wave value (s) which is the difference as discussed in parts e and f. Plots should appear somewhat sinusoidal with peak equal to unity (at s_{ref}) and remainder between zero and one.

      (a) 0 ohms (short circuit)   **(done previously in parts e & f)**
      (b) 200 ohms
      (c) 50 ohms (matched load)

5.3.2   Part 2: Measure Voltage Standing Wave Ratio (VSWR) using Slotted Line
Objective: Determine the VSWR at 1GHz CW for the loads of paragraph 5.3.1e.

a. Using the standing wave pattern measurements, compute the VSWR for each of the loads in 5.3.1g at 1 GHz. VSWR is obtained by computing the difference (in dB) between the peak (s_{ref}) and minimum (s_{min}) of the standing wave and converting from dB. VSWR values should always be greater than one.

b. Compare measured VSWR with theoretical values calculated using equations 1 and 2 (assume slotted line has no loss and Z_0 of the transmission line is 50 ohms)

5.3.3   Part 3: Transmission Line Loss Measurement using the Power Meter
Objective: Measure transmission line (coaxial cable) loss vs frequency directly using a power meter.
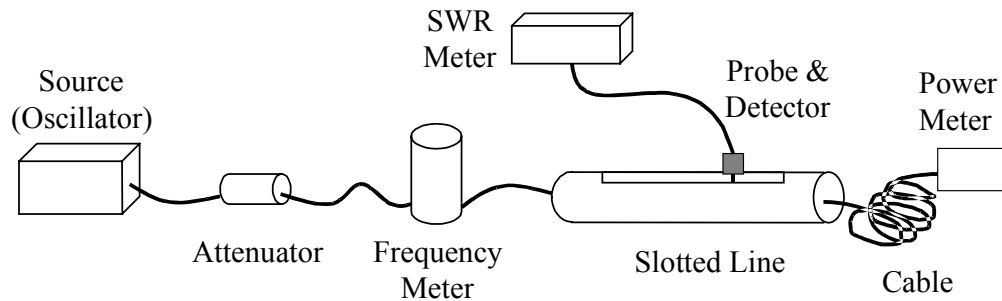
Figure 3: Test setup with coaxial cable with power meter.

a. Refer to Figure 3. Calibrate the digital power meter as follows:
 Plug the power sensor into POWER REFERENCE OUTPUT.
 Ensure POWER REFERENCE is OFF (button out).
 Set meter to dB Measurement.
 Zero the meter by depressing ZERO button until reading stabilizes.
 Set CAL FACTOR % per the chart on the power sensor for the 50MHz calibration signal.
 Press POWER REFERENCE ON (button in) to get 50MHz calibration signal.
 Ensure measurement reads 1.0mW or 0dBm. If not adjust CAL ADJ screw.
 Switch POWER REFERENCE to OFF (button out) when done.
 Unplug the power sensor from POWER REFERENCE OUTPUT.

b. Use the power meter to measure the power out of the slotted line (load end). This is the input power into the transmission line (coaxial cable). Connect the transmission line (coaxial cable) to the end of the slotted line and measure the output power at the end of the line (cable). The difference between power in dBm at the input and the output of the transmission line is the line loss in dB.

c. Measure line loss at the frequencies listed on Data Sheet 3. Ensure CAL FACTOR % on the power meter is set per the chart on the individual power sensor for the frequency being used.

d. Find the attenuation specifications for cable being tested. Plot measured loss and published loss specifications vs frequency on the same graph and compare.

6.0 PLOTS, HINTS AND SUGGESTIONS

The following plots should be made and included in your writeup.

Plot	Paragraph	Description
1	5.3.1	Standing Wave Patterns for 0, 50 and 200 ohm loads
2	5.3.2	Bar Chart of VSWR Measured & Theoretical VSWR vs Load
3	5.3.3	Coax Cable Loss, specifications/measurements vs frequency

DATA SHEET 1: STANDING WAVE PATTERN MEASUREMENTS

50 ohm Load			200 ohm Load			0 ohm Load		
Reference Value at Max (s_{ref})			Reference Value at Max (s_{ref})			Reference Value at Max (s_{ref})		
Slotted Line Position (cm)	s (dB)	V/V_{max}	Slotted Line Position (cm)	s (dB)	V/V_{max}	Slotted Line Position (cm)	s (dB)	V/V_{max}

DATA SHEET 2: Voltage Standing Wave Ratio (VSWR)

Frequency:_____ Hz   Square Law Detection (VSWR dB for 4dB attenuation):_____dB
                                                                                              (usually 3.7 to 4.1dB)

Z_L (Ohms)	VSWR Measured from Slotted Line				
	$s_{max} = s_{ref}$ (db)	s_{min} (db)	VSWR (dB)	VSWR	VSWR Calculated From Load Values
0					
50					
200					

DATA SHEET 3: TRANSMISSION LINE LOSS MEASUREMENTS

Frequency (MHz)	Cavity Frequency Meter (GHz)	PART #3 T-LINE LOSS FROM POWER METER MEASUREMENTS		
		P_{in}	P_{out}	Loss (dB)
950				
1000				
1100				
1200				

PULSES ON TRANSMISSION LINES

1.0   OBJECTIVE

Demonstration of time domain properties of signal reflection and transmission at impedance discontinuities on a transmission line. The following areas will be investigated:

Part 1: Effect on Source Pulse when Transmission Line Cable is attached.
Part 2: Cable Length Measurement by Time Domain Reflectometry
Part 3: Estimate Z_0 of the Transmission Line by Varying Source Impedance (R_G)
Part 4: Investigate the effects of Varying Load Impedance (R_L)
Part 5: Investigate the effects of Pulse and Reflections Overlap.

2.0   EQUIPMENT

The schematic diagram of the experiment is shown in Figure 1. Configurations for various portions of this experiment are on following figures. Lab staff uses Figure 1 to setup the equipment.

Item	Quantity	Description
1	1	Pulse Generator, Data Pulse 101
2	1	Oscope, 2 channel, external trigger (Tek 475, 2336, 7000 series)
3	4	BNC-BNC Test Leads, 50 ohms
4	1	Adapter Box, Metal (Drawer B-D3)
5	18	(2ea); 0,10,15,24,36,51,75,100,150 ohm Banana loads (R_S & R_L)
6	1	RG-11A/U Coax Cable
7	1	N-Banana adapter
8	2	Banana-BNC adapters
9	1	N-BNC Adapter
10	1	Single Banana Connection Extension

Figure 1: Pulses on a transmission line equipment setup.

3.0   INTRODUCTION

Previous experiments have dealt with time-harmonic voltages on transmission lines. In the case of continuous waves (CW), after a short transient time, the incident and reflected waves exist over the entire length of the line. They add and cancel depending on their relative phases and oscillate with a ωt time dependence. Standing waves result because the incident and reflected exist simultaneously. On the other hand, if a very short pulse is transmitted, then the incident and reflected fields will not exist over the entire length of the line.

In this experiment, the time domain properties of signal reflection and transmission at impedance discontinuities will be investigated using voltage pulses injected onto a coaxial transmission line. Knowledge of these properties becomes important in applications that interface high-speed communication signals between different pieces of equipment and cabling such as in computer networking. A signal propagating down a transmission line will be partially reflected if the load is not matched to the characteristic impedance of the line. For example, if the impedance discontinuity were the interface between a cable and a piece of electronic equipment, then not all of the transmitted power would get to the equipment. Furthermore, the reflected power can be reflected a second time at the source end of the line and transmitted back to the load (a second time around signal).   Thus the load would receive two signals: the original one plus a reflected one that is delayed in time. This effect is often seen on cable or closed circuit television systems as the familiar "ghosting" effect where multiple images of the same scene are displayed only slightly offset. Another consequence of impedance mismatching can be shown in computer network interfacing. Signal reflections from mismatches can result in confused signaling and needless bandwidth consumption. Thus the need for terminating ethernet connections.

This experiment uses a pulse generator to send narrow voltage pulses down a length of coaxial transmission line (T-Line for short). The roundtrip pulse travel time from the cable's source end to the load end and back is greater than the time width of the pulse, but is less than the period between pulses. This condition permits the original and the reflected pulses to be observed before a new source pulse is sent.

Two impedance discontinuity points on this circuit will be investigated. One at the input to the transmission line, the other at the loaded end of the T-line, as shown in Figure 2.   The behavior at the T-line input is modified by changing the source (generator) impedance (R_G). This is done by inserting a series resistance (R_S) into the circuit at the breakout box. T-line output impedance is modified by changing the load resistance R_L
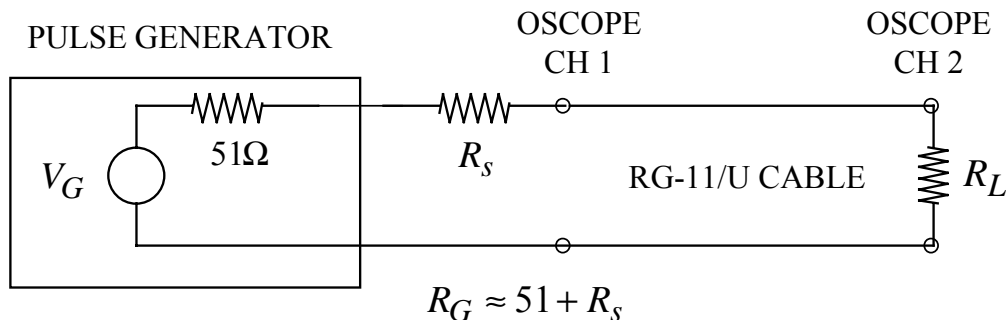

$$R_G \approx 51 + R_s$$

Figure 2: Circuit diagram for pulses on a transmission line.

Oscilloscope waveforms (voltage vs. time) are observed at both the source (sending) and load (receiving) ends. The observed pulses will not be perfect rectangular shapes due to attenuation and distortion effects of the cable at higher frequencies. However, this effect can be neglected as long as we carefully define the leading edge of the pulse, which is used to measure the time at which the pulse arrives. Various terminations will be used as called for in the instructions. Waveform sketches and reflection diagrams will be made illustrating pulse reflections and their dependency upon the relationship of the impedance discontinuity.

4.0   <u>THEORY</u>

Figure 3 shows a transmission line circuit with a d-c voltage source. Immediately after the switch is closed, the total resistance across the battery is $R_G + R_o$. Therefore, the fraction of source voltage across the input of the line is

$$V_o^+ = \frac{V_G R_o}{R_G + R_o}$$

This is the amplitude of the wave incident on the load for a lossless line. At the load, the reflection coefficient is $\Gamma = \dfrac{R_L - R_o}{R_L + R_o}$ and therefore the amplitude of the reflected wave is

$$V_o^- = \Gamma V_o^+ = \frac{\Gamma V_G R_o}{R_G + R_o}$$

If the generator at the input side is not matched to the transmission line impedance, then another reflection occurs at the input of the line. Mathematically there are an infinite number of reflections if $|\Gamma| > 0$. However, in practice they decay very rapidly for small reflection coefficients. More details are discussed in the text.
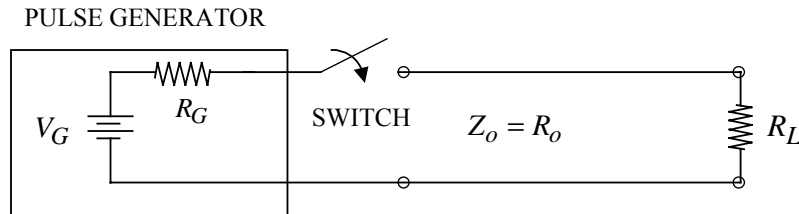

Figure 3: Step voltage on a transmission line.

A reflectometer is an instrument used to measure distances based on time delays. For example, if a buried Transatlantic cable were to break, an estimate of the location of the break can be obtained by measuring the round trip time delay of a short pulse. A break most likely would appear as a short or open, providing a large reflection source. If a pulse is sent down the line with a phase velocity v_p and a large reflection measured a time T_d later, then the estimated distance of the break from the input is $d = \dfrac{v_p T_d}{2}$.

5.0   PROCEDURE

5.0.1   Setup - Source pulse setting (Unloaded)

Pulse Repetition Rate	100 kHz ($T=10\mu$sec)
(also called pulse repetition frequency, PRF)	
Pulse Width	0.2 μsec
Pulse Amplitude	6 volts

This is the waveform required from the pulse generator. To obtain this waveform, use the following procedure. This procedure provides initial settings for the equipment. You will need to adjust the pulse generator and measure its output using an oscilloscope (Oscope) connected as shown in Figure 3 to the pulse breakout box. The breakout box provides a interface to measure signals coming out of the pulse generator and going into the coaxial cable transmission line. The settings are provided to get you started, you may need to adjust equipment as necessary.

a. Connect system as shown in Figure 4, for initial setting and measurement of the pulse waveform. Energize pulse generator and Oscope. Set pulse generator settings and adjust using the Oscope to measure. Set instrument controls to first view the pulse train on the Oscope and then an individual pulse.

   Pulse Generator settings:

POS AMPLITUDE: Approx 4	REP RATE: 1.0MHz vernier fully CCW
PULSE DELAY: 0.1 µS vernier fully CCW	PULSE WIDTH: 1.0 µS, vernier fully CCW
GATED MODE: nongated	PULSE MODE: SGL

   OscillOscope (Oscope) Settings: *(adjust time & volt scales as needed during experiment)*

TIME/DIV:	2 µs/div for pulse train *(to measure Pulse Repetition Rate-PRF)*		
	0.1 µs/div for single pulse *(to measure pulse width)*		
	Coupling: AC;	Trig Source: external TRIG MODE: AC	
	Ch 1 Volt/div: 2	Vert Mode: ALT	Ch 1 Coupling: AC

b. Pulse Repetition Rate (PRF):   Switch Oscope time/div controls to see pulse train (2 µs/div). Ensure that the Oscope trigger is set for external. While viewing the waveform on the Oscope, adjust pulse generator REPETITION RATE vernier to get the required PRF (time between pulses).

c. Pulse width, delay and amplitude: Set Oscope time base controls to display a single pulse (0.1 µs/div). Adjust pulse generator verniers for: DELAY, to align leading edge of pulse with the first vertical graticule line; WIDTH for required pulse width: POSITIVE AMPLITUDE, for required pulse amplitude.
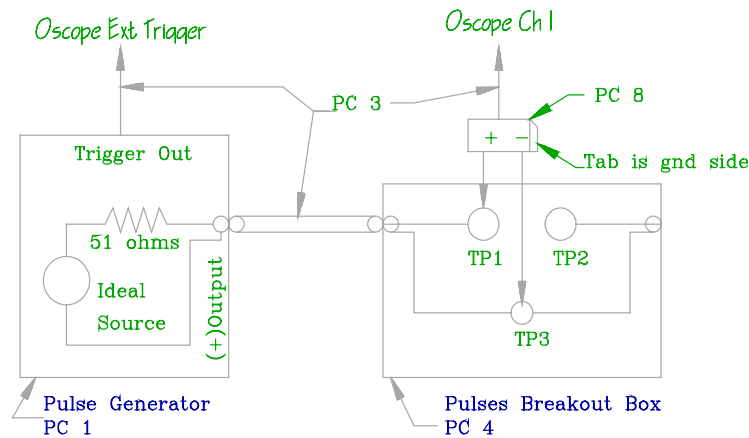
Figure 4: Setup to measure input pulse.

5.1 Part 1: Effect on Source Pulse due to Connecting Transmission Line Cable

The RG-11A/U coaxial cable is connected to the output of the pulse generator (at breakout box) and the effect on the open circuit source pulse previously measured (in 5.0.1) is investigated.

a. Connect system as shown in Figure 1 and set Oscope to measure the reflected pulse waveform. Insert a short for R_S, total source impedance is the pulse generator internal impedance (R_G=51ohms). Set R_L to be an open circuit.

b. Measure the pulse amplitude at the input to the transmission line (Ch 1). Has it changed from open circuit pulse amplitude previously set, if so why?
Hint: (1) you are no longer measuring an open circuit voltage (V_{OC} is not V), and

(2) measured amplitude is the sum of the incident and reflected pulses, $(V^+ + V^-)$.

c. Using the values for source pulse and incident pulse amplitudes, estimate a value for the characteristic impedance of the RG-11A/U transmission line.

OC Source Pulse: 6 Volts (set previously V_{OC})

Measured Pulse at Input:_____ Z_0 Estimated:_____

5.2 Part 2: Cable Length Measurement by Time Domain Reflectometry

Assuming v_p= 0.66c (manufacturer's data), calculate the length of the RG-11A/U coaxial cable by measuring the time delays of the reflected pulse.

a. Connect System per Figure 5 and set Oscope to measure the reflected pulse waveform. The displayed waveform is a time history of one pulse bouncing back/forth on the transmission line (RG-11A/U cable). Set R_L as an open circuit for largest reflection, R_S as a short circuit.
b. Separately sketch Ch1 & Ch2 reflected pulse waveforms. Use same time scale but draw them using separate vertical scales *(e.g. draw Ch1 above, Ch2 below)*. Annotate each waveform with the one way and roundtrip times. Show formulas and calculations of the cable length below the waveform sketches.

c. Estimate the cable's physical length by measuring cable coil diameter and counting number of coils.

TDR Cable Length:_____ Estimated Length:_____

5.3 Part 3: Estimate Z_O of the RG-11A/U Cable by Varying Source Impedance (R_G=51 + R_S)

Estimate the characteristic impedance, Z_o, of the transmission line by viewing the Oscope waveforms as the source impedance R_S is varied. Load impedance is set as an open circuit to provide a fully reflected pulse from the cable end.

a. Connect equipment as shown in Figure 1. Set Oscope to measure the reflected pulse waveform. Set R_L as an open circuit for largest reflection.
b. Match the line to the equivalent generator by varying R_S. Hint: Observe the pulse reflected from the source (on Ch 2), note when it is eliminated. Record matching value for the series resistance R_S. Impedance matching Source-Cable:

R_S :_____ Total R_G :_____

c. When the source is matched to the cable, sketch the waveforms (Ch1 & Ch2). Draw the reflection diagram for 2 roundtrips below the waveforms, provide values for each reflection coefficient. Add a brief discussion of the magnitudes of the waveforms observed.
d. Increase R_S such that the total source impedance is $2Z_o$. Sketch the waveforms (Ch1 & Ch2). Draw the reflection diagram for 2 roundtrips below the sketch, provide values for each reflection coefficient. Add a brief discussion of the magnitudes of the waveforms observed.

5.4 Part 4: Investigate the Effects of Varying Load Impedance (R_L)

Source impedance (R_G) will be matched to the transmission line and load impedance varied, so that the effects on the reflected pulses can be observed.

a. Connect equipment as shown in Figure 1. Set Oscope to measure the reflected pulse waveforms from Ch1 & Ch2. Set R_S such that $R_G = Z_o$.
b. Substitute the following values for R_L with $R_G = Z_o$:

      (1) Open circuit   (2) $2 Z_o$
      (3) Short circuit   (4) $1/2 Z_o$.

For each case, sketch the waveforms (Ch1 & 2) noting the values for source and load impedance. Draw the reflection diagram for each case below the waveform drawing. Provide a short explanation justifying the voltage amplitudes and polarities recorded for each waveform.

5.5   Part 5: Case of Incident and Reflected Pulse Overlap

Matched source to the line ($R_G = Z_0$) set with $R_L = \infty$ (open), gradually increase pulse width to 1 μsec (from 0.2 μsec). Sketch the waveforms, draw reflection diagrams and explain the effects

when pulse width is 1 μs. Repeat for R_L as a short.

a. Install the proper value for R_S to set $R_G= Z_0$. Remove any R_L to set it open circuited.
b. Gradually increase pulse width by adjusting the pulse generator WIDTH vernier, observe the waveforms and comment on the effects.
c. Increase pulse width to 1 μs. Sketch the resulting waveforms and voltage reflection diagrams.
d. Repeat a, b and c with R_L as a short circuit.

6.0   QUESTIONS

6.1   Summary of Data Analysis and Graphs

The following list summarizes the graphs to be made. Figure 6 provides an example of the Waveform and Voltage Reflection Diagrams. Provide circuit values of the loads used in the pulse amplitude measurements. Show calculations of reflection and transmission coefficients and the calculated values for the voltage pulses at the measured locations. Note and provide comments on any discrepancies between your calculations and measurements.

| Part	Name of Plot	Type
5.2	Time Domain Reflectometry	Waveform & Voltage Reflection Diagrams
5.3c	Varying $R_G=Z_0$, R_L = open circuit	Waveform & Voltage Reflection Diagrams
5.3d	Varying $R_G=2Z_0$,R_L= open circuit	Waveform & Voltage Reflection Diagrams
5.4a	$R_G=Z_0$, Varying R_L = open circuit	Waveform & Voltage Reflection Diagrams
5.4b	$R_G=Z_0$, Varying $R_L = 2Z_0$	Waveform & Voltage Reflection Diagrams
5.4c	$R_G=Z_0$, Varying R_L= short circuit	Waveform & Voltage Reflection Diagrams
5.4c	$R_G=Z_0$, Varying $R_L =1/2\ Z_0$	Waveform & Voltage Reflection Diagrams
5.5c	Pulse Overlap (R_L = open)	Waveform & Voltage Reflection Diagrams
5.5d	Pulse Overlap (R_L= short)	Waveform & Voltage Reflection Diagrams
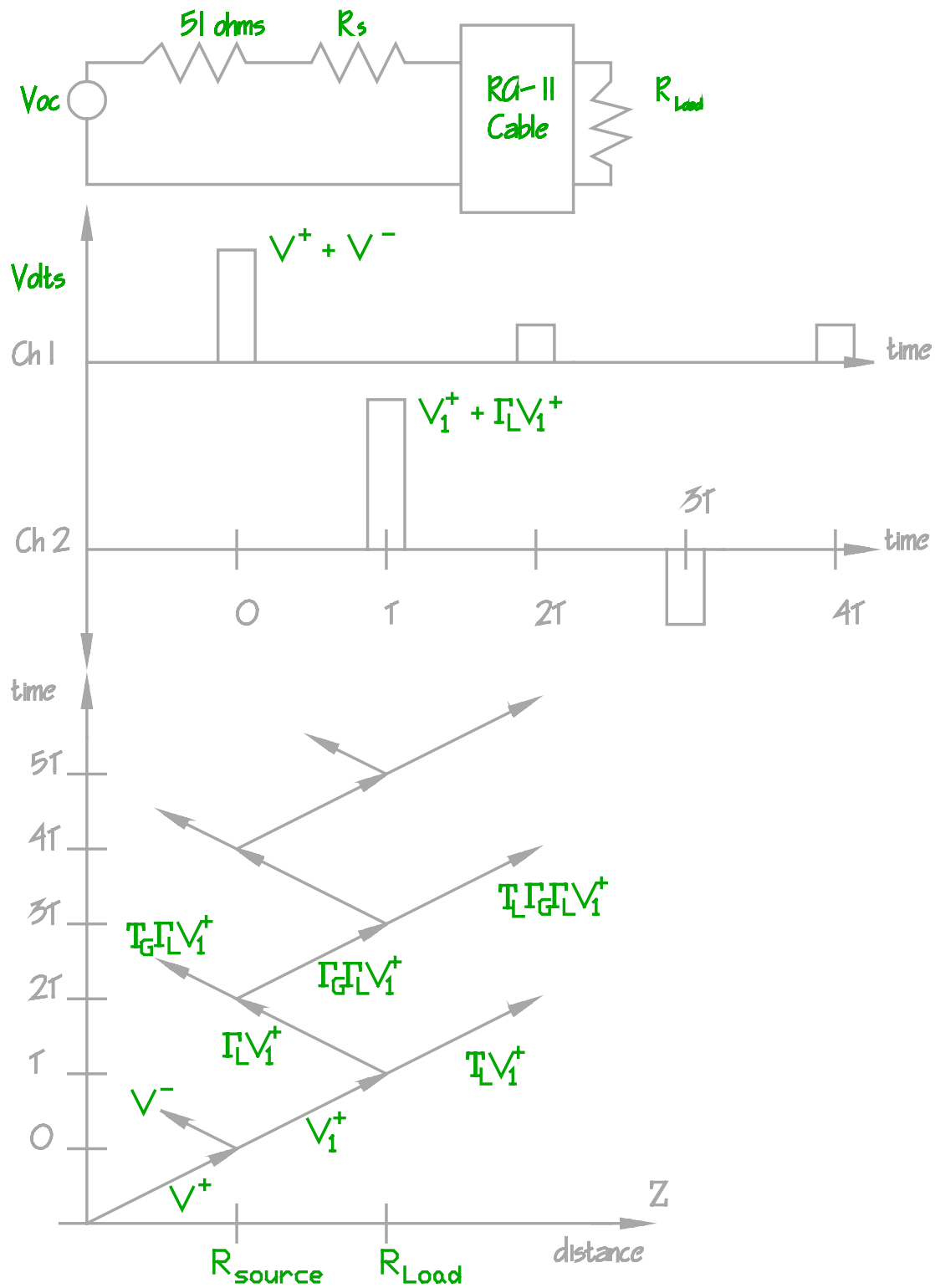
Figure 6: Example of a reflection diagram.

NAVAL POSTGRADUATE SCHOOL
Monterey, CA

SLOTTED LINE IMPEDANCE MEASUREMENT

1.0   OBJECTIVE

Determine the impedance of a load at several different frequencies from slotted line measurements of the standing wave ratio (SWR) and locations of equivalent load planes. Two loads (1 coaxial & 1 circuit resistor) are measured over a frequency band (950-1300 MHz) and the results plotted on the Smith Chart.

2.0   EQUIPMENT

Setup is shown in Figure 1.

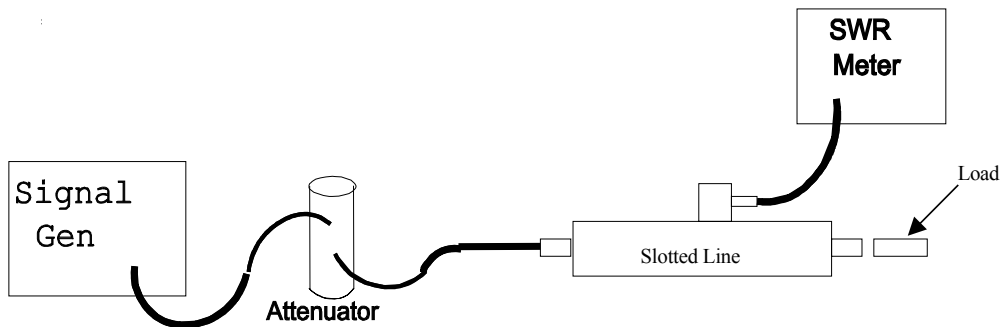| Quantity	Description
1	HP 8660 Signal Generator with HP86220A RF Section (10-1300 MHz)
1	Texscan Corp RA-50, 0-10 dB attenuator
1	HP 805C Slotted Line (0.5 - 4.0 GHz)
1	HP 415E SWR Indicator
1	Load: 200 Ohm GRC load + GRC to N adapter
1	Load: 51 Ohm banana plug + banana to BNC + BNC to N adapters

Figure 1: Test setup for impedance measurement.

3.0   INTRODUCTION

The slotted line data can be used to determine the impedance of an unknown load. A measurement of the SWR and the distance from a voltage minimum to the load is required. Using the Smith Chart, one enters (starts) with $Z_{min}=1/S$ at the plane of the voltage minimum and rotate the appropriate electrical distance to the plane of the load. At this point the normalized load impedance is read from the chart.

It is not generally easy to accurately determine the physical distance from a voltage minimum to the load plane. Therefore, the line is first shorted and the positions of the voltage nulls are found and recorded. These null positions are locations where the impedance is exactly the same (assuming

negligible loss) as the impedance at the load plane. This is true because impedance is repeated every half wavelength on a lossless line and the voltage nulls are spaced every half wavelength starting from the short at the load plane. These positions are called equivalent load positions. In practice, the voltage minima for an unknown load are found and the distance from a voltage minimum to an equivalent load position is determined.

In this experiment, the measurement procedure described above will be used to determine the impedance of several loads for the frequency range from 950 MHz to 1300 MHz. The effects of geometry and the various adapters will be determined.

4.0   THEORY

A slotted line can be used to measure the unknown impedance of a load. Measuring the SWR along with the shift in the null locations when the load is replaced by a short, provides enough information to compute the complex load impedance. The details of the measurement are discussed in the most textbooks. See for example Ulaby, Chang, or Pozar (the latter is reproduced as Appendix H). The process of calculating the impedance values from the measured data is most easily performed is a Smith chart, a graphical tool designed for transmission line calculations.   The Smith chart procedure is described in lecture and also summarized in Appendix H.

5.0   PROCEDURE

5.1   Preparation

Read the following Microwave Lab Help Sheets. Note the SWR meter reads out in negative dB.
- dB vs dBm   - Using the Slotting Line (0.5-4GHz)
- Measuring VSWR   - Using the Cavity Frequency Meter
- Reading the SWR (Standing Wave Ratio) Meter

5.2   Lab Setup

Ensure the setup is as shown in Figure 1. Sketch the lab setup for reference. Equipment should have the following settings:

Sweep Oscillator Settings		SWR Meter Settings
Band:	0.01-2.4GHz	Input: XTAL IMPED HIGH
Mode:	CW (CW/CW Marker Knob illuminated)	
Marker:	off	
ALC:	INT	
Modulation	1KHz SQ Wave (Switch on Back)	
Power:	+11 dBm	

5.3   Measurements

5.3.1   Set the sweep generator frequency to 950 MHz. Conduct the following to obtain the data needed to determine the impedance of the two loads at 950 MHz:

a. Connect a matched load (50 ohm coaxial) and tune the slotted line for square law detection (see *Using the Slotted Line (0.5-4 GHz)* for the procedure).

b. Replace the matched load with a coaxial short circuit load. Using the slotted line, record the positions of all nulls. If null point drops off the SWR meter scale (< -50dB), then find a point on each side of the null with the same SWR value. The midpoint between these equal SWRs is the null position. Record null locations on both Data Sheets 1 and 2.

c. Replace the short with the 200 ohm coaxial load. Measure the locations and the SWR values for each null (remember that in dB, SWR= $V_{max} - V_{min}$). Record values on Data Sheet 1.

d. Replace the short with the 51 ohm resistor load (on a banana to N type adapter). Measure the locations and the SWR for each null. Record values on Data Sheet 2.

5.3.2   Conduct the above steps for each frequency listed on Data Sheets 1 and 2.

5.3.3   Using the data measured using the slotted line, plot the impedance curve on the Smith Chart for each Z_L (assume Z_0 is 50 ohms). Comment on the results.

6.0   SUGGESTIONS

You may ask the Laboratory technicians to a sweep your loads using the HP8510 Vector Network Analyzer System. An appointment will be necessary. The Network Analyzer can produce an accurate Load Impedance Smith Chart (if calibrated properly) to which you can compare your plots.

DATA SHEET 1: SLOTTED LINE IMPEDANCE MEASUREMENTS

200 OHM COAXIAL LOAD

Freq (M Hz)	(With Short)			(With Load)			SWR of Load in dB		
	Null 1	Null 2	Null 3	Min 1	Min 2	Min 3	SWR Null 1 (dB)	SWR Null 2 (dB)	SWR Null 3 (dB)
950									
1000									
1100									
1200									
1300									

CALCULATED DATA

D_i = the Distance from the load to the first voltage minimum ($Null_i$ -Min_i); SWR = $10^{(SdB/20)}$

Freq (MHz)	D_1	D_2	D_3	D_{ave}	S_{ave}(dB)	SWR
950						
1000						
1100						
1200						
1300						

DATA SHEET 1: SLOTTED LINE IMPEDANCE MEASUREMENTS

51 OHM RESISTOR LOAD

Freq (M Hz)	(With Short)			(With Load)			SWR of Load in dB		
	Null 1	Null 2	Null 3	Min 1	Min 2	Min 3	SWR Null 1 (dB)	SWR Null 2 (dB)	SWR Null 3 (dB)
950									
1000									
1100									
1200									
1300									

CALCULATED DATA

D_i = the Distance from the load to the first voltage minimum (Null$_i$ -Min$_i$); SWR = $10^{|Sdb/20|}$

Freq (MHz)	D_1	D_2	D_3	D_{ave}	$S_{ave}(dB)$	SWR
950						
1000						
1100						
1200						
1300						

Millimeter Wave Link

1.0 OBJECTIVE

The purpose of this lab exercise is to demonstrate how the path difference and antenna physical parameters of a microwave transmission system affect its loss. A miniature instrumented microwave link is operated and measurements of power transmitted/received, frequency, antenna size and distance between antennas are used to evaluate system loss.

2.0 EQUIPMENT

A K-band microwave line of sight (LOS) link uses two small parabolic reflector antennas is assembled and located in the Microwave Lab (SP-419). The microwave link is fixed to a large plywood board with the distance between antenna on the order of 2-3 meters. The system is instrumented with a frequency meter and power meters so that power measurements can be made using 10dB K-band directional couplers to redirect a portion of the incident power to the power meter heads. Most of the equipment is K-band waveguide. A frequency of 23.8 GHz will be used.
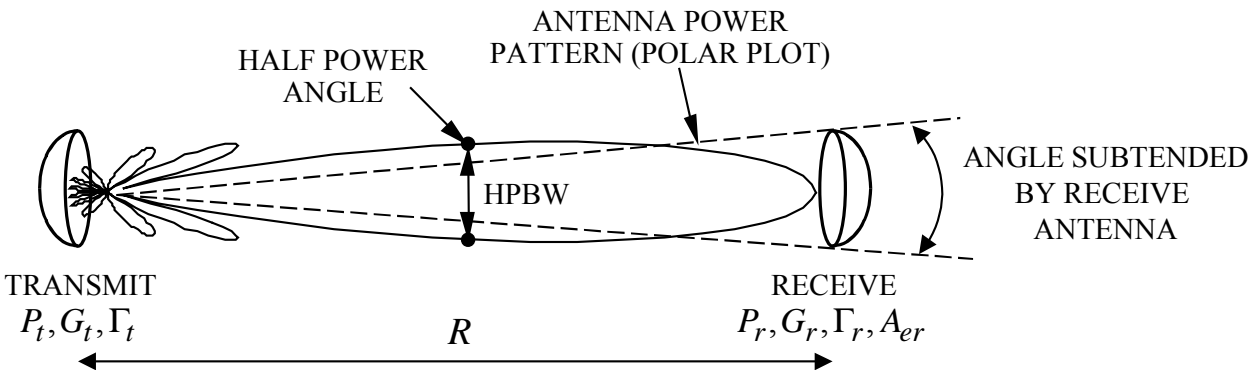

Figure 1: K band microwave link.

3.0 INTRODUCTION

The transmitter consists of a K-band signal source (HP8350A Sweep Oscillator with HP83570A RF Plug-in, 18 – 26.5 GHz) feeding a parabolic reflector antenna. The wave radiated by the transmitting antenna is received by a second parabolic reflector antenna positioned at a distance R *(Meters)*. The polarization of the transmitting and receiving antennas is set by the polarization of the dominant mode in the feed waveguide.

4.0 THEORY

The power received, P_r (Watts), is related to the power transmitted by the Friis equation

$$P_r = \frac{P_t G_t A_e}{4\pi R^2}\left(1-|\Gamma_t|^2\right)\left(1-|\Gamma_r|^2\right)pL = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}\left(1-|\Gamma_t|^2\right)\left(1-|\Gamma_r|^2\right)pL$$

where:

P_t = available input power to the transmitting antenna (Watts, convert to dB if needed)
Γ_t = reflection coefficient in the transmitting feed line
G_t = Gain of the transmitting antenna in the direction of the receiver (convert to dB if needed)
p = Polarization mismatch factor
G_r = Gain of the receiving antenna in the direction of the transmitter (convert to dB if needed)
λ = free-space wavelength (meters)
Γ_r = reflection coefficient for the receiving antenna
A_e = effective area of the receiving antenna
L = loss factor

The maximum gain of a reflector antenna can be estimated by

$$G = \frac{4\pi A}{\lambda^2} e = e\left(\frac{\pi D}{\lambda}\right)^2$$

where e is the antenna efficiency and D is the diameter of the reflector. The efficiency for a reflector depends on spillover loss, blockage, and the aperture taper distribution. The aperture taper distribution is determined primarily by the radiation pattern of the feed antenna. For the antennas used in this experiment, the aperture distribution can be represented by a cosine-squared on a pedestal, which has a taper efficiency of about 0.88 and a 3 dB beamwidth that is given approximately by $\theta_B = 65\lambda/D$ (degrees). The overall loss factor, L, is about 50% ($L=0.50$). These formulas hold when the observer is sufficiently far from the antenna. The rule of thumb for the minimum far-field distance is usually taken to be $\frac{2D^2}{\lambda}$.

5.0   PROCEDURE

5.1   Preparation

5.1.1   Express the Friis transmission equation in dB (i.e., the received power in dB as a sum of dB quantities).
5.1.2. Draw a precise diagram of the system with the antenna sizes and distance between antennas labeled. Pay close attention to the orientation of the directional couplers, their ratings and how power measurements are effected. Note the presence of the K-131 isolator, why is it installed ?
5.1.3   Examine and determine how to operate the following equipment on the microwave link:
   •HP8350A Microwave Sweep Oscillator (Sweeper) with HP83570A RF Plug-in
   •HP-K382A Variable Attenuator
   •General Microwave 476 Power Meters (at both ends)

•3K-44 Waveguide switch
•HP5343A Digital Frequency Counter

5.2   Equipment Setup and Initialization

5.2.1   Energize equipment as follows:
a. HP8350A Sweeper: turn power switch ON.
b. GM476 Power Meters: turn power switch ON.
c. HP5343A Frequency Counter: turn power switch ON.

5.2.2   Calibrate both power meters for waveguide operation at 23.8GHz as follows:
a. Ensure that no RF power is incident to the meter power heads (sweeper RF Plug-in "RF" push button switch center light to unlit, power off, position).
b. On the GM476 Power Meter, set the switch to OPR and hit zero button to clear, needle should go to zero. Now set switch to CAL, needle goes to approximately 8 (for waveguide power heads) or 10 (for coaxial power heads). A self-contained 10 kHz oscillator enables calibration of the power meter and TFT (Thin-Film-Thermoelectric) power head without disconnecting the power head from the RF system under measurement. The RF from the source must be turned off during calibration. You may not get more than a reading of 7 or so, which is O.K. If the reading is off, have lab technician adjust using the CAL screw.
c. Set switch back to OPR setting.
d. Read CAL FACTOR setting from chart on power head label. (23.8GHz). This should be interpolated from the series of small round indentations in the power head calibration chart label. Dial CAL FACTOR setting into the power meter.

5.2.3   Set up Sweeper for 23.8GHz CW operation and Variable Attenuator to 3dB as follows:
a. Ensure sweep selector switch is set to CW.
b. Adjust the waveguide variable attenuator to 3dB.
c. Place waveguide switch (3K-44) in position to direct power to the HP5343A digital frequency counter. Position one of the 2 curved or the 1 straight "flow" lines on the waveguide switch from the bottom port (directional coupler flange) to either the top port (power head) or right port (frequency counter).
d. Adjust sweeper frequency to 23.8GHz. Adjust sweeper RF Plug-in power level to 10.0 dBm (+10 dBm). Press sweeper RF Plug-in "RF" push button switch center light to lit, power on, position. Record the frequency measured from the digital frequency counter:

_____ GHz

5.3   Measurements

5.3.1   Measure power on transmit side of link as follows:
a. Set the waveguide switch to direct power to the power meter head.
b. Adjust the power meter scale and record the power measured in mW and dBm below:
Transmit Side Power_____mW (_____dBm)

5.3.2   Measure the power on the receive side of link as follows:
Adjust the power meter scale and record the average power measured in mW and dBm below:
Receive Side Power_____mW (_____dBm)

5.4   Calculations

5.4.1   Compute the transmission loss in dB $10\log(P_r / P_t)$ from your measured values of power. Note that the power measured is not the actual transmitted or received power. Why?

5.4.2   Using measured dimensions (in Meters), estimate the boresight gains (also convert the gains to dB) of the reflector antennas using a 50% aperture efficiency.

5.4.3   Estimate the 3 dB beamwidths of the reflectors in degrees and compare to angles subtended by each reflector. Does each antenna lie completely within the half power beamwidth (HPBW) of the other? Calculate the minimum far-field distance from the reflectors and compare it to the actual path length.

6.0   QUESTIONS

6.1.   Using your estimated antenna gains and measured propagation distance, compute the transmission loss (also convert the loss to dB) and compare to that measured. Assume $|\Gamma_t| = |\Gamma_r| = 0$ and $p = 1$. Justify these assumptions.

6.2.   Discuss the results from the perspective of what factors could cause differences between the measured and computed transmission losses.

NAVAL POSTGRADUATE SCHOOL
Monterey, CA

WAVEGUIDE COMPONENTS

1.0   OBJECTIVE

Provide familiarization with X-Band WR-90 waveguide components.
     Part 1: Measure using a slotted line and plot on a Smith Chart the complex impedance of a waveguide iris over the frequency range 8.5 to 12GHz.
     Part 2: Demonstrate operation of a waveguide directional coupler and a waveguide isolator at 10GHz using power meter measurements. Ensure that power meter head being used has low VSWR first.

2.0   EQUIPMENT

The experimental setups are shown in the Figure 1.

| Quantity	Description
1	HP8620C Sweep Oscillator with 86250D RF Module (8-12.4 GHz)
1	HP809B Slotted Line (8-12.4 GHz)
1	HP440 Detector
1	HP415E SWR Meter
1	HP436A Power Meter with HP8481A Sensor and Cord
1	HPx532A Frequency Meter
1	HPx382A Variable Attenuator
2	HPx281A Waveguide to N Crystal Adapters
2	Uniline X-12-25 Waveguide Isolator
1	HPx910B 50 ohm Wedge Termination
1	HPx752C WR(90) Waveguide Directional Coupler
1	WR(90) Waveguide Extension (approx 4in long)
2	X-Band Waveguide Iris' (1 short plate, 1 inductive)
1	BNC-BNC Test Lead
1	N to N Test Lead
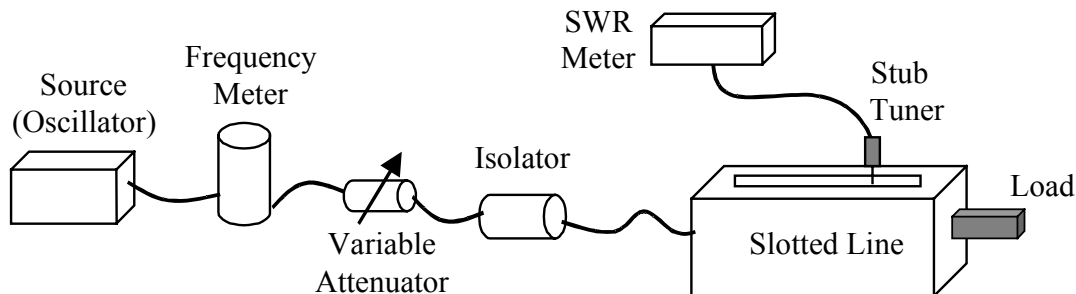
Figure 1: X-band waveguide slotted line measurements for VSWRs of shorting plate and inductive iris.

3.0   INTRODUCTION

At frequencies from 1 to 300 GHz, waveguide components are commonly used to perform various functions in microwave systems. The physical size of a component scales with wavelength, but the construction of a given component is generally the same for all frequency bands. The standard rectangular waveguides are all designed to operate with only the TE_{10} mode propagating. Other modes may be present near discontinuities, but they are below cutoff and decay rapidly with distance down the transmission line (waveguide).

In this experiment, WR-90 (also know as X-Band) waveguide and waveguide components will be used. WR-90 guide operates over the frequency range from 8.2 to 12.4GHz and has dimensions $a =$ 0.9 and $b = 0.4$ inches. This waveguide size is often used because it is "optimum" with regard to size, cost and the ease with which measurements can be made in this frequency range.

4.0   PROCEDURE

4.1   Part 1: Measure and Plot the Complex Impedance of a Waveguide Iris Load

a. Ensure setup is as shown in Figure 1. Place a wedge (50 ohm) termination onto the end of the slotted line. Set signal generator to 8.5 GHz, CW.
b. Tune slotted line for square law detection (read "Using the Waveguide Slotted Line (8-12.4GHz). Record the square law reading for 4dB attenuation.
c. Replace the matched load with a shorting plate. Measure and record on Data Sheet 1 the locations of VSWR nulls with the slotted line shorted. These are considered "Equilvent Load Planes." Calculate guide wavelength (λ guide) and enter on Data Sheet 2.
d. Measure the operating frequency and compute wavelength using the cavity frequency meter. Note some lower frequencies drop off frequency meter scale, use setting reading from signal generator or measure using a microwave frequency counter. Record on Data Sheet 1 and 2.
e. Remove the shorting plate and install an inductive iris on the end of the slotted line and terminate it in a matched load. **NOTE: The inductive iris is NOT square.** Ensure iris is aligned properly. Inductive iris has same width as the smaller dimension of the waveguide but small width than the larger dimension of the waveguide.
f. Measure the VSWR of the inductive iris. Measure and record the locations of the minima of the standing wave due to the inductive iris load. Record values on Data Sheet 1.
g. Using the VSWR of the inductive iris, calculate the input reflection coefficient and record on Data Sheet 2. Calculate the angle (in degrees) that the load plane moved and record on Data Sheet 2.
h. Repeat the above steps for the remaining frequencies (9, 10, 11 and 12 GHz).
j. Using the input reflection coefficient and angle, plot the impedance and admittance loci of the inductive waveguide iris on a Smith Chart for the operating band (8.2 to 12 GHz, start at 8.5GHz).
k. If time and resources are available, you may ask the Lab Director to make a plot of the complex impedance of your waveguide iris with wedge load using the Vector Network Analyzer. Compare this plot vs yours.

NOTE: Only <u>qualified</u> Microwave Lab Technicians may operated the Vector Network Analyzer. This will require a scheduled appointment and a difficult TRL (Transmission, Reflect, Line) type of calibration.
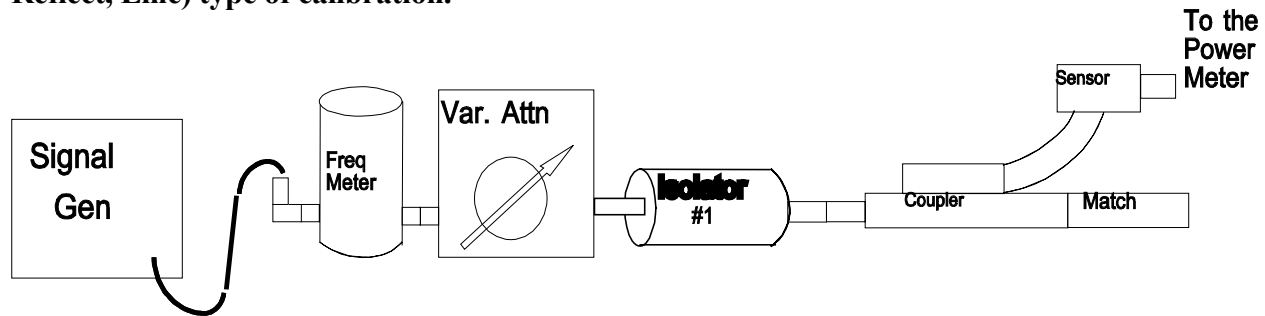

Figure 2: X-band coupler measurements of coupling and directivity.

4.2 Part 2: Operation of Waveguide Directional Coupler and Waveguide Isolator (10GHz)

Power measurements into and out of an X-band Waveguide Directional Coupler and a Waveguide Isolator are made to illustrate their operation. The VSWR of the power meter thermistor mount and wedge termination are first measured to ensure that these devices are well matched to the circuit. All work will be done at 10 GHz (CW).

a. Ensure setup is as shown in Figure 1. Place a wedge (50ohm) termination onto the end of the slotted line.   Set signal generator to 10 GHz, CW.
b. Tune slotted line for square law detection (read "Using the Waveguide Slotted Line (8-12.4GHz). Record on Data Sheet 3 the square law reading for the 4dB attenuation.

NOTE: DO NOT EXCEED THE POWER LIMIT OF THE THERMISTOR MOUNT.
          (Ensure that power from the signal generator is not above 10dBm.)

c. Measure the VSWR of the power meter thermistor mount and the waveguide wedge termination. Record values on Data Sheet 3.
d. Remove the slotted line and replace it with a second isolator.   It is no longer used.
e. Using the power meter, measure the insertion loss and the isolation of isolator #2 at 10 GHz. (Note: isolators are directional, look for arrows or input/output designations). Record insertion loss and isolation on Data Sheet 3.
f. Remove isolator #2 and set up the equipment as shown in Figure 2 with a 10 dB coupler and a matched termination.   Directional couplers direct some of the power coming in Port 1 to the curved arm. Amount of power directed is call coupling (a 3dB coupler would be a power splitter). The amount of power decrease coming out of Port 2 is the insertion loss. Terminate any "open" ends of the coupler with a matched impedance (wedge) to prevent reflections from occurring. Measure the coupling and Insertion loss at 10GHz and record on Data Sheet 3. Do these values agree with a 10dB coupler specification?
g. Reverse the coupler. Only the power from port 1 is supposed to couple with the curved arm. The measure of power from Port 2 coupling with the curved arm is called directivity. Measure the directivity at 10GHz and record on Data Sheet 3. Terminate any "open" ends of the coupler

with a matched impedance (wedge) to prevent reflections from occurring.

5.0   PREPARATION, HINTS & SUGGESTIONS

Read over the following Microwave Lab Help Sheets prior to attempting the experiment:

• dB vs dBm
• Using the Waveguide Slotted Line (8-12.4 GHz)
• Measuring VSWR
• Using the Cavity Frequency Meter

FYI (...for your information)

Isolators are used to allow RF energy to flow in one direction only. The measure of how well they do this is called isolation. Insertion loss is the power loss through the isolator (P_{in}-P_{out}). Isolation is the power allowed backwards through the isolator.

Directional Couplers direct some of the power coming in Port 1 to the Port 3. How much power is directed is called coupling (a 3dB coupler would be a power splitter, why is that?). The measure of how much power from Port 1 couples with Port 3 is called directivity.

PITFALLS TO AVOID

➢ Waveguides are aligned using bolts through 2 holes and held together with spring loaded sheet metal clamps. Like fasteners/bolts are diagonal to each other. Be cautious when installing and removing the sheet metal clamps (AKA Finger Pinchers). Use the funny looking tool that resembles a cross between pliers and a hammer.   After you compress the spring keep your fingers away from the sheet metal clamp otherwise you may end up performing a strange tribal dance.
➢ Ensure waveguide parts are properly aligned. Mounting flanges are not labeled which is top or side so you'll need to look at the cavities to check alignment.
➢ Calibrate the slotted line after changing frequencies.   Adjust the stub tuner on the slotted line when changing frequencies. Check for square law detection.
➢ Know what the precision attenuator is set to when making SWR measurements. Sometimes people forget to move the attenuator back to zero after calibrating the slotted line.
➢ Power measurements... use the power meter with power sensor. For power loss, measure the power going into the device under test (known as the DUT) by replacing the DUT with the power sensor. Then replace the DUT and measure the power out of the DUT.
➢ Isolators are directional. Ensure the arrow or input/output markings are orientated where you want them.
➢ Waveguide inductive iris is not square. Correct orientation of the inductive iris in the waveguide is important. The waveguide narrower dimension (top/bottom) walls should align with iris, sides (wider dimension) will be brought in by the iris.

Data Sheet 1
Part 1: Complex Impedance of a Waveguide Inductive Iris using a Slotted Line
Measured Data

Freq GHz	Square Law Detector reading (3.7-4.1 dB)	Freq Meter (GHz)	LOAD IS SHORTING PLATE			LOAD IS THE INDUCTIVE IRIS					
			Standing Wave Null Location with Short as Load			Standing Wave Minimum Location with Iris as Load			VSWR of IRIS in dB largest Vmax & each Vmin		
			Null 1 (cm)	Null 2 (cm)	Null 3 (cm)	V_{min1} (cm)	V_{min2} (cm)	V_{min3} (cm)	SWR_{min1} (dB)	SWR_{min2} (dB)	SWR_{min3} (dB)
8.5											
9.0											
10.0											
11.0											
12.0											

Data Sheet 2
Part 1: Complex Impedance of a Waveguide Inductive Iris using a Slotted Line
Calculated Data

Cavity Meter		Distance minimum moved between short & iris loads						VSWR of IRIS		Smith Chart Data	
freq (GHz)	λ_{meter} (cm)	D 1 (cm)	D 2 (cm)	D 3 (cm)	D ave (cm)	λ_{guide} (cm)	Towards Generator or Load	SWR_{ave1} (dB)	SWR_{ave}	$\|\Gamma\|$	θ

Notation:

λ_{guide} is the guide wavelength,   (example: λ_{guide} = distance between Null 1 and Null 3)

Di is the distance from the load minimum to the shorted circuit minimum (ex: D1= Null1 - Vmin1)
Γ is the reflection coefficient of the iris load,

$| \Gamma |= (SWR-1) / (SWR+1)$
$SWR = 10^{SWR(dB)/20}$
$\theta = 180 \; deg*\{1 - 4 * (D_{ave} / \lambda_{guide}) \}$

Data Sheet 3
Part 2: Operation of Waveguide Directional Coupler and Waveguide Isolator (10GHz)

Square Law Detection 3.7-4.1 dB	VSWR Measurements		Isolator Measurements		Waveguide Directional Coupler		
	Thermistor Mount (S)	Waveguide Wedge (S)	Isolation (dB)	Insertion Loss (dB)	Coupling	Insertion Loss	Directivity